

APPLICATION FOR
UNITED STATES LETTERS PATENT

FOR

**SURFACE MOUNT POWER SUPPLIES
FOR STANDARD ASSEMBLY PROCESS**

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RELATED APPLICATION

The present invention is a non-provisional filing based on Provisional Application Serial No. 60/298,908 filed on June 19, 2001 and entitled "Design of Surface Mount
5 Power Supplies For Standard Assembly Processes."

BACKGROUND OF THE INVENTION

1. Technical Field of the Invention

10 The present invention relates generally to a surface mountable power supply and specifically to an interconnect and method of interconnection that provides a robust physical and electrical connection between the power supply module and an end user circuit card.

15 2. Prior Art to the Invention

A distributed power architecture employs many small board mounted power supply modules in place of a few larger and more centralized power supply modules. A power supply module is mounted directly to the end user's circuit card that requires the power. A need exists for a method of placing the power supply module on the end user
20 circuit card in an economical fashion. In other words, the method should minimize the number of manufacturing steps required for the placement. However, the method must also provide a robust physical connection to the end user circuit card, so that subsequent handling does not dislodge it. The connections between the power module and the end user's circuit board must also be robust enough to handle high current loads.

25 Conventional power supply modules may be constructed as a unitary, encapsulated package, having one or more rows of leads, with the power supply module enclosed in a metal case. The leads allow the module to be coupled to a circuit card while the metal case contains attachment mounts for an external heat sink. The power supply module often includes one or more power devices (e.g., transistors or diodes) in
30 thermal communication with the metal case, one or more magnetic devices (e.g., transformers or inductors) providing electrical isolation and energy storage and one or

more circuit boards containing passive electronic devices to provide, among other things, control and monitoring functions.

Power devices and magnetic devices that require thermal management due to their high power dissipation may be mounted on a metal circuit board employing insulated metal substrate technology, for example, a THERMAL CLAD substrate manufactured by the Bergquist Corporation of Minneapolis, Minn. Electronic devices such as passive devices that do not require thermal management may be mounted on either the metal circuit board or on a conventional FR4 circuit board. The FR4 circuit board may then be mechanically and electrically coupled to the metal circuit board to facilitate electrical communication and power flow between the various parts of the power supply module.

The leads of the power supply module are mechanically and electrically coupled to either the FR4 circuit board or the metal circuit board. The power supply module is typically encapsulated in a plastic or metal case that is filled with an encapsulant to protect the internal components of the power supply module from contaminants and perhaps to improve heat flow between the internal components and the case.

The aforementioned encapsulated package design, however, suffers from a number of deficiencies. At least two circuit boards, the metal circuit board and the FR4 circuit board, are required to accommodate the constituent components of the power supply module. Employing multiple circuit boards increases both complexity and cost of the power supply module. Further, the encapsulation can place additional stress on the component solder joints, leading to premature joint failure.

Conventional encapsulated and open frame power supply modules are often mounted to the end user's circuit card via through-hole pins. For example, **FIGS. 1 and 2** illustrates a through-hole pin connection. An end user's circuit card typically contains a large number of surface mount components. In fact, the power supply module is often the only through-hole mounted component on the circuit card. A separate or additional manufacturing step is thus required to mount the power supply module to the circuit card, thereby increasing the complexity and overall cost of the electronic assembly incorporating the circuit card. **FIG. 1** illustrates an exploded isometric view of prior art power supply **100**. The power supply **100** advantageously employs planar magnetic devices (one of which is designated **130**) to decrease the size of the power supply **100**.

The power supply 100 includes a conventional FR4 circuit board 110 containing conductive traces for interconnecting electronic devices mounted thereto. The planar magnetic device 130 has windings 120 formed from a portion of the conductive traces. A core of the planar magnetic device 130 (including first and second core halves 133, 136) is disposed through apertures of the circuit board 110 and proximate the windings 120.

The power supply 100 further includes a metal case 140 having a base and four side walls, thus forming a five-sided reservoir to receive the circuit board 110 therein. Alternatively, the metal case 140 may be formed without one or more of the side walls to allow air flow through the power supply 100. The air flow may advantageously assist in dissipating heat from the constituent components of the power supply 100. In the illustrated embodiment, the metal case 140 is an insulated metal substrate such as a THERMAL CLAD substrate, having an electrically insulating layer 145 and an electrically conductive layer 150, in addition to the metal layer. Portions of the electrically conductive layer 150 may be removed, allowing the remaining portions to form conductive traces for interconnecting the electronic devices. The metal case 140 further has attachment points for coupling to an external heat sink. In the illustrated embodiment, the attachment points are internally threaded posts (one of which is designated 185) protruding from the metal case 140.

The power supply 100 further includes a plurality of semiconductor power devices (e.g., a switching device, one of which is designated 160) having a body coupled in thermal communication with the metal case 140 and terminals (one of which is designated 165) couplable to the conductive traces of the circuit board 110. The power device 160 may be soldered to the metal case 140 via a conductive pad 155, with the solder joint providing thermal coupling between the power device 160 and the metal case 140. Soldering the power device 160 to the metal case 140 enhances an automatic assembly (e.g., for repeatability purposes) of the power supply 100.

The power supply 100 further includes an encapsulant 170, located within the reservoir, that provides a thermally conductive path to direct heat generated by the electrical components of the power supply 100 towards the metal case 140. The encapsulant 170 may be located in only a portion of the reservoir or may substantially fill the reservoir.

FIG. 2 illustrates a side cut away view of the power supply **100** of **FIG. 1** mounted on an end user's circuit card **10**. The power supply **100** is designed to be through-hole mounted on the end user's circuit card **10** using conventional soldering techniques. Since the end user may subject the circuit card **10** to the reflow soldering process after the power supply **100** has been mounted thereon, it would be advantageous for the power supply **100** to be able to survive the reflow soldering process. The power supply **100**, therefore, employs high temperature solder. The end user's reflow temperature profile may then be set to a temperature sufficient to melt the solder between the power supply **100** and the circuit card **10**, but not sufficient to melt the high temperature solder joints within the power supply **100**. Further, the encapsulant **170** within the power supply **100** can cause solder displacement during solder reflow processes, resulting in component displacement.

While the use of high temperature solder will allow the power supply **100** to survive the reflow soldering process, the constituent components of the power supply **100** are necessarily subject to high temperatures during the assembly of the power supply **100** as the components are soldered to the circuit board **110**. The high temperatures may degrade the functionality of the components or, in extreme cases, cause some of the components to malfunction. Therefore, what is needed in the art is a power supply module that may be manufactured using, for instance, a standard tin/lead (e.g., 60/40 or 63/37 Sn/Pb) solder composition, thus avoiding the disadvantages associated with the use of high temperature solder.

An alternative to through-hole connections is a surface mount connection. With surface mount connections, component pins do not have to penetrate holes in a circuit board. Instead, component leads are coupled to a circuit board and subjected to a reflow soldering process. One difficulty with the surface mount approach lies in the need for the power supply module to pass through the reflow soldering process as it is mounted to the end user's circuit card. The reflow soldering process can subject the power supply module to extreme stresses, possibly melting all of the power supply module's internal solder joints and possibly degrading the functionality of the constituent components of the power supply module. The electronic devices of the power supply module may shift

or even decouple from the FR4 circuit board during the reflow soldering process, possibly destroying the functionality of the power supply module.

Efforts to alleviate the stresses caused by the reflow soldering process have often centered on the use of high temperature solder for the power supply module's internal solder joints. The end user's reflow temperature profile may be set to a temperature that is sufficient to melt the solder between the power supply module and the circuit card, but is too low to melt the high temperature internal solder joints. This may require special processing techniques and materials, such as employing solder and component plating to ensure high reliability. Also, it may be necessary to secure heavier components using glue or other mechanical fasteners to ensure that the components remain in place during the reflow soldering process.

FIGS. 3 and 4 illustrate an open frame power module **200** that can be surface mounted to the end user's circuit card. **FIG. 3** provides an isometric view of power supply **200**. The power supply **200** employs an open frame design and includes a substrate **210** (e.g., FR4) having opposing upper and lower conductive layers. The substrate **210** further has a number of vias located therethrough that provide an interconnection between the upper and lower conductive layers. The power supply **200** further includes a magnetic device **220** (e.g., a planar magnetic device) mounted on the substrate **210**. The planar magnetic device **220** may be a transformer, an inductor or a combination thereof having windings formed from a portion of the conductive traces on the upper and lower layers of the substrate **210** and a core disposed through apertures of the substrate **210** and proximate the windings. The power supply **200** further includes a number of electrical components (not shown) having leads mounted on pads formed on the upper conductive layer. The power supply **200** further includes a number of electrical components (one of which is designated **230**) having leads mounted on pads (one of which is designated **250**) formed on the lower conductive layer. The electrical components **230** are mounted on the substrate **210** using a standard tin/lead solder composition, located proximate the leads of the electrical components. The solder will transition to a liquid state as the power supply **200** is brought to a reflow temperature, subjecting the electrical components **230** to forces capable of detaching the electrical components **230** from the substrate **210**.

The power supply **200** places small components on the lower conductive layer. The small components have a sufficiently low weight such that a surface tension of the solder is sufficient to maintain the components in contact with the lower conductive layer as the solder is subjected to a temperature sufficient to transition it to the liquid state during the reflow soldering process. Components that are too large to be held in place by the surface tension of the solder are placed on the upper conductive layer. The power supply **200**, therefore, can be directly reflow soldered along with other surface mount components on an end user's circuit card. Thus, the use of glue or other mechanical fasteners to ensure that the components remain in place during the reflow soldering process is avoided.

The power supply **200** further includes a number of inter-substrate conductive mounts (one of which is designated **240**) coupled to the lower conductive layer. The conductive mounts **240** are adapted to mount the power supply **200** to an end user's circuit card (or an adjacent substrate) and provide a conductive path there between. The conductive mounts **240** are composed of a material having a melting point above the solder reflow temperature. In the illustrated embodiment, the conductive mounts **240** are hollow copper balls that are plated with tin/lead and are approximately 125 mil in diameter. The copper balls illustrated are manufactured by Ball Chain Manufacturing Co. of Mount Vernon, N.Y. and by Bead Industries of Bridgeport, Conn.

FIG. 4 illustrates a side cut away view of the power supply **200** of **FIG. 3**. The power supply **200** is mounted to an end user's circuit card **10** using the copper balls as conductive mounts **240**. Since the power supply **200** is designed to be surface mounted on the end user's circuit card **10** using a reflow soldering process, small components **230** are mounted on the lower conductive layer of the substrate **210** while larger components **270** are advantageously mounted on the upper conductive layer. The small components **230** may thus be maintained in contact with the lower conductive layer by a surface tension of the solder as the power supply **200** is subjected to the reflow soldering process.

The substrate **210** has a number of circular vias (one of which is designated **20**) located therethrough that provide an interconnection between the upper and lower conductive layers. Of course, the vias **20** need not be circular. The conductive mounts **240** may be surface mounted to the substrate **210** at the vias **20**. The geometric simplicity

of the copper balls advantageously allows the conductive mounts 240 to be placed on the
vias 20 in any orientation, the vias 20 assisting in centering or locating the conductive
mounts 240 thereon. As the conductive mounts 240 are mounted to the substrate 210 of
the power supply 200 by a reflow soldering process, solder may substantially fill the vias
5 20, providing a low impedance path through each via 20. Since the conductive mounts
240 may carry a large amount of current, the low impedance path created by the solder
within the via 20 and proximate the conductive mount 240 reduces a resistive loss
experienced by the power supply 200.

In any surface mount application, it is desirable to use automated equipment to
10 pick-and-place a surface mount component. This is particularly true with a large
subassembly such as the open frame power supply 200 of FIG. 3. To enable a
component or subassembly to be used with pick-and-place equipment, a designer should
provide a substantially flat surface that is compatible with a vacuum pick-up head of the
pick-and-place equipment. More specifically, the substantially flat surface should
15 preferably be located in the center of mass of the subassembly to properly balance the
subassembly during the pick-and-place process. One way to provide the substantially flat
surface is to leave an open spot (unpopulated with components) on the substrate 210 at
the center of mass of the subassembly. The open spot should have sufficient clearance to
accommodate the vacuum pick-up head. Leaving an open spot, however, is not conducive
20 to improving power density. Another way to provide the substantially flat surface while
improving the power density of the power supply 200 is to locate a sufficiently large
component (e.g., power transistor 270) at the center of mass of the power supply 200.
Since the large component 270 is placed on the substrate 210 using pick-and-place
equipment, a top surface of the large component 270 is compatible with the vacuum pick-
25 up head and may thus be employed to provide the substantially flat surface, allowing the
subassembly to be compatible with the pick-and-place equipment. Alternatively, a
special component whose primary purpose is to provide the substantially flat surface may
be incorporated into the subassembly.

One problem not thoroughly addressed in the prior art is the need to maintain co-
30 planarity even when there is warpage of the power module. Another problem not
addressed by the prior art is the need to minimize warpage of the power module's circuit

board. Addressing both problems would improve the reliability of the connection between the power module and the end user circuit card, especially when the power module is placed using a pick and place machine. An interconnect used to allow for a secure connection with a solder paste used on the end user's circuit card. Further, the

5 tolerances between the interconnects should never exceed the thickness of even a modestly thin layer of solder paste.

SUMMARY OF THE INVENTION

The present invention relates to an improved surface mount power supply that can withstand the rigors of the manufacturing process and still create sturdy and robust

5 connection to a user's circuit card. The open frame power module uses a U-shaped interconnect rather than a spherical interconnect. In one embodiment, the U-shaped interconnect can have a hole through one surface to allow the wicking of solder. The wicked solder provides a sturdier connection that is more likely to survive subsequent reflow processes. Further, the hole allows for degassing when the solder paste is heated.
10 The power module is also built on a thick FR4 board. The thicker board is less likely to warp during subsequent heating. Further, a U-shaped interconnect is less likely to shift during mounting than a spherical interconnect.

The invention is a method of designing a surface mount power module that is compatible with standard customer assembly and reflow processes. The proposed
15 invention does not require a post-lead forming process or count upon co-planarity adjustments during the customer reflow soldering operation. Furthermore, the invention does not employ a mechanical lead frame for interconnects between the power supply and the end user's circuit card.

The invention further comprises a tight-tolerance interconnect that is pick and
20 placed during the first side power module assembly. The tight tolerance interconnect is required to ensure good lead coplanarity. The interconnect does not require a hole in either the end user's or power supply manufacturer's board which serves to conserve board real estate and eliminate coplanarity tolerance due to variations in the size of the drill hole. The power module is built on a substrate that is sufficiently thick to minimize
25 coplanarity tolerance due to board warpage or relaxation during reflow soldering processes.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

5 **FIGS. 1 and 2** illustrate a prior art power supply with through-hole pin connections;

FIGS. 3 and 4 illustrate a prior art surface mount power supply;

FIG. 5 illustrates a surface mount power supply in accordance with the present invention;

10 **FIGS. 6A to 6D** provide detailed views of the interconnects of the present invention.

FIG. 7 shows the connection between the interconnects of the present invention and a solder paste placed on the end user's circuit card; and

15 **FIGS. 8A and 8B** illustrate the use the conductive tracings within the FR4 circuit board and their use to increase the stiffness of the circuit card.

DETAILED DESCRIPTION OF THE DRAWINGS

This invention includes both a power module assembly that addresses the deficiencies of the prior art as well as an interconnection element used to couple the power module to an end user's circuit card. **FIG. 5** provides a simplified perspective view of a power module in accordance with the present invention. The power module **300** is an open frame design. Elements can be mounted on the circuit board **302**. In one embodiment, the circuit board is built in multiple layers. Each layer has a conductive surface, typically a circuit pattern of copper. For example, an FR4 board can be used. A circuit pattern is etched onto each layer, and then the layers are placed on top of each other with vertical conductive paths between the layers. Each layer might be approximately 6-8 mils in thickness. Thus, a twelve layer board might be approximately 80 mils in thickness.

In one embodiment, the circuit board **302** is sufficiently thick to minimize coplanarity tolerance due to board warpage or relaxation during the reflow soldering process. For example, the board might be between 60 and 100 mils in thickness, and preferably 80 mils in thickness. At temperatures of approximately 210 degrees Celsius, a board of this thickness will warp less than 1 to 2 mils per inch of board from a centerline. In preparing the circuit tracings on each level of the board **302**, a maximum amount of copper is left on each layer to increase the stiffness of the board, and thus its resistance to warpage. Substantially equal amounts of copper on each layer also contribute to minimizing warpage.

A pair of planar magnetic cores **304** and **306** engage the circuit board **302** generally at aperture **318**. The planar cores **304**, **306** can be held in place by clip **308**. Element **320** can act as a suitable surface for a pick and place machine. A winding can be etched on the exposed surfaces of aperture **318**. The windings can be part of a circuit that interacts with the planar magnetic cores **304**, **306**.

A plurality of interconnects **310** can be placed on one side of the circuit board and be used for coupling the power module **300** to the end user circuit card **10**. A plurality of mounting pads **30** are located on the circuit card **10**. A solder paste is placed on these pads **30** and the interconnects **310** are then placed onto the solder paste. Heat is applied that melts the solder past and allows it to flow around the interconnect. Upon cooling,

the solder paste freezes thereby coupling the interconnect to the conductive mounting pad 30.

FIGS. 6A and 6B provide additional detail of one embodiment of the interconnects 310. As mentioned above, the board can be made of multiple layers of individually etched circuits. For example, layers 360 and 362 can each have a conductive layer on one side. This layer can be selectively etched to form a portion of the overall power module circuit. The interconnect 310 acts as a lead for that circuit, allowing the power module to power the end user's circuit card. Alternatively, one or more of the interconnects can simply be used to support the power module in a spaced apart position from the end user circuit card 10. The interconnect 310 is generally U-shaped with at least one side wall 312 and a contact surface 316. In one embodiment, the contact surface 316 can have at least one hole 314 there through. The hole 314 allows solder paste to flow into the interconnect and form a stronger physical bond. Also, the hole 314 allows for degassing from the solder paste. However, the present invention includes a U-shaped interconnect with or without hole 314. Alternatively, side slots 340 as shown in **FIG. 6C** can be used. Alternatively, a T-shaped interconnect 350 can be used as shown in **FIG. 6D**. The T-shaped interconnect can have a contact surface 352 that is coupled to board 300 and a prong 354 that contacts the solder past 40. A U-shaped interconnect could also be used with a T-shaped interconnect.

While shown as a perfectly flat board, power module 300 usually is not. Uneven heating of the board during solder reflow processes can cause the board to warp slightly, perhaps by only a few mils. Likewise, the interconnects 310 should also be of equal and precise height, but variations can occur due to manufacturing inconsistencies. Further, the end user board 10 should be perfectly flat, but is rarely so. In sum, there are tolerances that must be addressed to ensure that each interconnect 310 makes positive and sustainable contact with the card 10. A solder paste 40 is placed on mounting pads 30. Errors in the dimensions and shapes of the board 302, interconnect 310, or card 10, can be subsumed within the depth of the solder paste 40. In other words, once the interconnects are mounted to the board 302, the contact surfaces 316 should all fall within the same plane. However, an error, such as seen in **FIG. 7**, results in one surface

316 being closer to the board 10. This error can be tolerated within the depth of the solder paste which is generally pliable and can conform around the interconnect 310.

FIGS. 8A and 8B illustrate the use the conductive tracings within the FR4 circuit board. The raw FR4 board includes a complete layer of copper cladding. A photo-resist can be applied to the copper and an image of the etch pattern is shined on the photo-resist. The areas exposed to light resist exposure and the unilluminated areas do not. The unilluminated areas are then rinsed removing the unexposed photo-resist and the copper beneath it. Layer 362 and 364 are shown. Layer 362 can have a winding pattern 370 as well as large expanses of copper. Likewise, layer 360, shown in **FIG. 8B**, can also have a winding pattern 380 and large expanses of copper 382. As mentioned above, it is advantageous to leave as much copper on the layer as possible to increase the stiffness of the board 302. Another advantage of leaving excess copper on each layer is that during heating and cooling, the thermal expansions forces experienced by the copper are balanced by those on each layer.

Those skilled in the art should understand that the previously described embodiments of the surface mountable power supply and related methods are submitted for illustrative purposes only and other embodiments thereof capable of surviving reflow are well within the broad scope of the present invention. Additionally, exemplary embodiments of the present invention have been illustrated with reference to specific electronic components. Those skilled in the art are aware, however, that components may be substituted (not necessarily with components of the same type) to create desired conditions or accomplish desired results. For instance, multiple components may be substituted for a single component and vice-versa. For a better understanding of a variety of power converter topologies employing discrete and integrated magnetic techniques, see *Modern DC-to-DC Switchmode Power Converter Circuits*, by Rudolph P. Severns and Gordon Bloom, Van Nostrand Reinhold Company, New York, N.Y. (1985); and *Principles of Power Electronics*, by John G. Kassakian, Martin F. Schlect and George C. Verghese, Addison-Wesley Publishing Company, Reading, Mass. (1991). The above-listed references are incorporated herein by reference in their entirety.

Although the present invention has been described in detail, those skilled in the art should understand that they can make various changes, substitutions and alterations herein without departing from the spirit and scope of the invention in its broadest form.

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